Chapter 9 – Working Memory

Introduction

Definition of working memory: The capability we have allowing us to co-ordinate mental operations with temporarily stored information during cognition.

Distinct from the concept of STM, but is linked to it.

Chapter is based on **Baddeley**'s 1986 account - plus developments of this model and the challenges to it newer evidence presents.

Human memory is multifaceted

Commonly talked about as if it is a single system (e.g. I have a good/bad memory) but the psychological evidence suggests otherwise - e.g. the oldest theoretical distinction is between STM (remember a phone number to dial after looking it up) and LTM.

Working memory goes beyond the concept of a short term store and includes out ability to perform mental operations - classic example is complex mental arithmetic. Evidence shows errors are made due to the delays imposed by sequencing operations (e.g. adding units, then tens, then hundreds … etc.) - **Hitch**. Combined attention of remembering the items and operating on them suggests working memory is limited in its capacity.

Distinction between STM and LTM

Memory for spoken words is different over short and longer time-spans and evidence from **Baddeley (1966)** was that immediate recall of phonetically similar words was poor but good for semantically similar words.

Also, 'span of immediate memory is only a few items (7 plus or minus 2) - **Miller;** Briefly presented stimuli are forgotten rapidly c.f. with better learned ones.

All these things imply (at least) two different memory stores - one short term, the other long term.

Murdock - modal model - reflected unanimity of though in late 1960s. STM = short term, limited capacity store; control processes used to maintain information in STM; STM gradually transferred to LTM.

Atkinson and Shiffrin - best known example of a modal account. Short term store is labelled as a ***working memory*** as it contains control processes such as rehearsal, coding, decisions and retrieval strategies which are optional - not automatic.

Support - the comprehension of 'garden path' sentences (e.g. "we painted the wall with cracks" - **Just and Carpenter** - evidence that low working memory capacity => more difficult for multiple possible representations to be maintained. However, **Caplan and Waters** argue comprehension requires more specialised resources than simply working memory.

Agreement short lived - challenges to the modal model were: (a) did the different strands of evidence converge on a unified account - e.g. different ways of estimating STM capacity give different answers (b) did STM really act as a working memory - neuropsychological evidence from KF (**Shallice and Warrington**) was that although he only had an auditory digit span of 2 items he performed normally of tests of long term learning & memory. The absence of impairment in KF's learning challenges the idea that working memory is required to support it.

Working memory as more than STM

Dual task paradigm used by **Baddeley and Hitch** to conduct an empirical investigation of STM to see if it acted as working memory. Interference between tasks should occur if they are competing for a common, limited capacity resource.

e.g. ability on verbal reasoning tests while remembering increasingly long digit sequences was impaired. Similar result found when the cognitive task was reading or learning lists for free recall. Concluded:

(a) An irrelevant STM task interferes with a wide range of cognitive tasks => consistent with the idea of a working memory combining temporary storage with ongoing mental operations.

(b) Working memory concept is more than STM - as if STM is 'filled', there is no catastrophic breakdown in concurrent cognition => working memory has some other resource(s) not shared with STM.

Further distinction between STM and WM - studies on individual differences. If two tasks have similar underlying psychological processes, a positive correlation between performance should be observed. **Daneman and Carpenter** - standard measures of STM (e.g. word span) do not require ongoing mental processing operations to be combined with storage.

Novel reading span test used instead - read unrelated sentences and remember the last word. Similar to standard measure of STM but in this reading span test they have to be remembered at the same time as performing the processing required by reading.

Daneman and Carpenter found reading span was well correlated with comprehension (fact questions, pronoun questions and verbal SATs) whereas word span was not. Argued results supported **Baddeley and Hitch** concept of WM - i.e. its ability to combine storage and mental operations.

However - criticism - **Daneman and Carpenter** correlations could be just an artefact of the processing operations themselves. e.g. **Turner and Engle** - operation span task - better predictor of reading comprehension than standard STM - despite operation span task (arithmetical calculations) being very dissimilar to reading. Supports idea of a WM common to a wide range of activities that combine processing with storage.

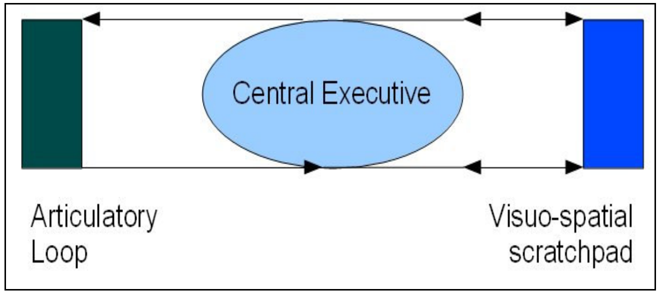
The structure of working memory

The **Baddeley and Hitch** result - high STM loads causes interference but loads of 2 or 3 items can be carried without much interference to the main task was taken to support the idea that working memory can be split into two parts.

As they also found an adverse sensitivity to phonemic similarity was a characteristic of STM and showed reasoning and comprehension were also sensitive it suggests they share a common factor.

The subsystems Baddeley and Hitch describe to account for these results consist of an ***articulatory (rehearsal) loop*** – roughly equivalent to the earlier concept of STM and a ***central executive***, that controls and co-ordinates a wide range of different mental operations. The central executive is seen as a limited capacity workspace which can either be allocated to temporary storage (so increasing the storage provided by the articulatory loop) **or** to control mental processes – all dependent on the current task.

An elaboration of this account adds a visuo-spatial scratchpad – to account for the observations from dual-task studies which suggest separate resources are available when a visual task is combined with a verbal task as these are less problematic than performing two verbal or two visual tasks simultaneously. This is **Baddeley**'s ***tripartite model***.



Neurological evidence for the separation of AL & VSS - **De Renzi and Nichelli** - Corsi span and auditory digit span can be impaired separately. Also supported by the knowledge that mental images as mnemonics also aid recollection. **Baddeley and Lieberman** - found visual mnemonics are disrupted by a spatial task (tracking a moving loudspeaker blindfolded) but not by a visual task (detecting changes in brightness.) The same result was not observed if the mnemonic strategy was rote rehearsal.

Other evidence is contradictory w.r.t. imagery – e.g. **Hitch, Brandimonte and Walker** – imagery performance better when superimposing two line drawings that are congruent to form a new image (e.g. both black on white) than if incongruent (e.g. one white on black) – good evidence that the images preserve information about visual appearances.

Logie – metastudy and review - suggested separate visual and spatial systems and that the spatial movement system can rehearse the contents of a visual store – the visuo-spatial equivalent of the articulatory loop. **Smyth and Waller** study of rock climbers suggest WM is probably even more sophisticated than this, as attempts to disrupt their ability to use visual, spatial and kinaesthetic information while they imagine a route they often climb shows additional complexities.

Alternative accounts to the tripartite model have been suggested to address subsequent theoretical concerns – for example, in the relationship between WM and LTM.

An alternative view is that WM is an activated region of LTM. **Cowan** cites domain expertise – for example, of chess players, whose WM skills are superior when working in their area of expertise. A separate executive system is still assumed – so the difference is one on the nature of backup storage (specialised buffers vs activated LTM).

Phonological working memory

AL is well understood because of the many exptmental manipulations that affect how it operates.

e.g. – phonemic similarity, discussed earlier.

Also: word length of items. Limit on STM span varies with length of items (higher for short words, lower for longer words) **Baddeley, Thomson and Buchanan** – contrary to **Miller**'s idea of fixed chunks.

Systematic relationship found between #words recalled and how many can be said out loud in around 2 seconds – consistent with the idea of a ***rehearsal loop***.

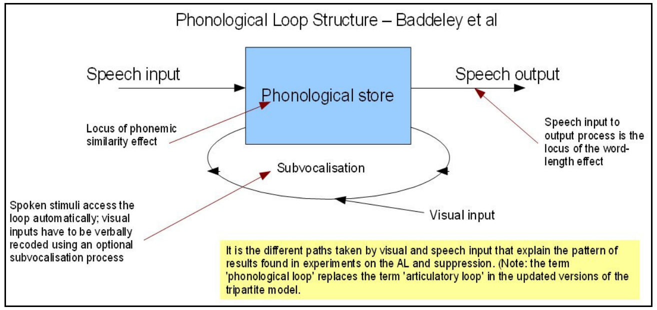
and … **Baddeley et al** – individual differences also affect STM span – faster speakers recall more words than slower ones.

Can also explain results of dual-task experiments where immediate serial recall is combined with articulatory suppression (saying the, the, the …). The primary task therefore has to be done without assistance from the AL – Baddeley's findings were consistent with articulatory suppression disrupting the AL.

Differences between recall of longer and shorter words and phonetically similar/dissimilar items is also removed by suppression.

However – effects of word length and phonemic similarity only nullified if items presented visually, not aurally. **Baddeley** – clarified this surprising result by continuing suppression during recall. This removes the word-length effect for auditory items but did not remove the phonemic similarity effect. Modified version of AL - the ***phonological loop*** - that results follows:

This two part model of the AL generates insight into developmental changes in STM as children mature.



Developmental and cross-linguistic differences

a. **Hulme et al** – study - as children get older, average level of recall increases proportionally with the rise in their average speech rate. Also, size of word-length effect in children of different ages mirrors the time taken to say words of different lengths. Clear empirical evidence for the PL model; also a possible explanation as to the developmental growth in memory span – i.e. if you can rehearse faster, you can recall more things.

b. Cross-linguistic differences in digit span (7.2 for English, 6.5 for Hebrew, 6.4 for Spanish and 5.8 for Arabic) are highly correlated with the rate at which the digits can be said - **Naveh-Benjamin and Ayres**.

c. Children aged 7+ (like adults) are poorer at recalling items of longer names for spoken words or pictures. Younger children show this only for spoken words – **Hitch et al**.

d. Young children find pictures harder to name during recall when they are visually similar; older children find this more difficult if the names of the pictures are phonemically similar – **Hitch et al**.

c. and d. provide further evidence that the recoding process is slow to develop, meaning young children have to depend more on visuo-spatial memory. There is a developmental progression from visual to phonological coding – related to reading ability.

The irrelevant speech effect

Finding: background speech disrupts STM for visually presented verbal stimuli.

Salamé and Baddeley – ignoring irrelevant speech more interfering than noise. Concluded unattended speech enters the phonological store – non-speech does not. A consistent further finding is that blocking verbal recoding of visual stimuli by suppressing articulation stops irrelevant speech being disruptive.

Challenged by research showing non-speech does cause interference, dependent on same factors as speech interference – e.g. steady state streams of noise are less disruptive than changing state streams – **Macken and Jones**. This suggests a broader explanation of interference is required – not specific to the verbal domain.

Not mutually exclusive – irrelevant speech may affect both a specific phonological mechanism as well as a more general one, such as serial ordering.

Neural basis

Challenge for any model is to explain selective impairments of memory. PV (**Vallar and Baddeley**) – auditory digit span of 2 items. Other abilities unimpaired. Found memory span for spoken items poorer when phonemically similar but unaffected by word-length. Concluded phonological store was damaged – as PV would not find subvocal rehearsal a useful strategy – so would not show the usual word-length effect. Her visual span was higher than her auditory span and unaffected by either phonemic similarity or word-length. PV may therefore have relied on visuo-spatial WM for remembering visual stimuli – parallel with young children where phonological loop development is not complete.

Neuroimaging techniques enable study of normal brains – e.g. **Paulesu et al** – PET study of location of phonological loop. Result suggested separate locations for storage and rehearsal. Locus of storage aspect of phonological loop corresponded to where PV was brain damaged.

[**Paulesu et al** experiment – 6 consonants followed by a probe letter – participants indicated if the probe had occurred in the sequence – test of phonological memory. Non-phonological memory tested by Korean character sequences. Broca's area implicated in phonological memory.]

Theoretical issues

Phonological loop model has been successful – but limitations becoming apparent in (for example) its power to explain the impact of irrelevant speech.

Lovatt et al – word-length effect may not after all be due to item's spoken duration as they found little or no effect of word-length if the phonological complexity of words tested is carefully controlled.

Developmental studies show rehearsal is not necessary for the word-length effect – as children around 4y.o. show such an effect when recalling spoken stimuli – at an age they are not able to use rehearsal strategies (**Hulme et al**).

Output delays can cause word-length effects too (without rehearsal) – e.g. **Cowan et al**.

Executive processes

Central executive – controls/co-ordinates mental operations within WM. **Baddeley and Hitch** – supervision of slave stores (e.g. phonological loop, visuo-spatial scratchpad) and interface to LTM.

Has also been described as an area of 'residual ignorance' or 'problematic' – **Andrade**. Danger of it being viewed as a reinvention of the homunculus; has links to the difficult concept of consciousness [ch. 15]

Central workspace

Evidence from experiments on measuring reading span could suggest that the limited span of WM reflects the capacity of a workspace or 'mental blackboard' - but further evidence is required to confirm this.

Towse et al - tested workspace hypothesis ('task sharing'?) in children - a decline in resources available to support processing should occur towards the end of a trial, as the number of items in the store increases (for reading, orientation, counting span tests.) No systematic decline found.

Towse et al - alternative hypothesis tested 'task switching' - children switch attention between processing and storage rather than sharing attention between processing and storage. Did this by manipulating the time period information had to be stored for while holding processing required constant. In line with their prediction, found spans were lower when time intervals were longer for all 3 types of task. Later research confirmed same effect in adults.

Spans are lower when operations are more complex - **Barrouillet and Camos**.

Hitch - some evidence of processing slowing down if storage load is increased.

Other things limit WM span - **de Beni et al** - individuals with low spans more often recall items from previous trials (intrusion errors).

So WM span probably does not reflect the capacity of a central workspace - more complex account required. The executive may be ***fractionated***, rather than being a single system.

Attention

Baddeley's later (1986) view of the executive very different from **Baddeley and Hitch** (1974).

Norman and Shallice - control of cognition and action involves two levels.

Lower level - learned schemata for routine actions, organised in parallel so compete with each other; they fire automatically in response to specific trigger stimuli. (e.g. hearing our own name spoken diverts our attention to the speaker.)

Higher level - supervisory attentional system - SAS - limited capacity; intervene to stop lower level schemata from firing despite its trigger being present.

Model explains 'utilization behaviour' (**Lhermitte**) in patients with frontal lesions (e.g. just placing a glass and bottle of water in front of a patient causes them to pour out a glass of water and drink it.)

Diary studies of slips in everyday life show these are often about making inappropriate but familiar action in a familiar context - e.g. putting on Wellingtons as if to work in the garden just by passing them in the hall when the task in hand was to go out to the car (**Reason**).

Norman and Shallice model explains such things as distraction inhibiting the functioning of the SAS.

Baddeley adopted this model for the executive - i.e. it becomes a purely attentional system rather than one of a workspace with processing + storage.

Investigated by **Baddeley** using random number/character generation experiments - to generate random sequences, supervised inhibitory control is required to stop us generating stereotyped sequences (e.g. ITN, BBC …). However, **Towse et al** - random generation is unlikely to be purely a measure of executive function and will involve other systems.

Fractionation

Baddeley (1996) - executive is separate but related functions dealing with different aspects of attention.

i.e. for:

- focusing
- dividing and switching attention
- using attention to access LTM

Empirical support for this model from Alzheimer's patients - exaggerated problems in combining concurrent tasks vs normal ageing, where focusing attention becomes more difficult.

Miyake et al - studied individual differences on attentional tasks - shifting attention, monitoring/updating information and inhibiting pre-potent responses. A three factor statistical model explained the outcomes better than simpler models => consistent with the idea EF is fractionated, ***but*** number and description of the fractions is not the same as **Baddeley**'s proposal!

Coherence and the binding problem

Binding problem: if visuo-spatial information about objects is stored separately from verbal information then the system requires some way of keeping track of which pieces of information refer to the same object.

Jones - uses this as a way of criticising **Baddeley**'s work as the assumption of separate subsystems creates a binding problem that is not addressed.

Evidence that irrelevant tones disrupt immediate memory for words (**Macken and Jones**) and that irrelevant speech disrupts memory for spatial sequences (**Jones et al**) - and in both cases it is the variability of the irrelevant stimuli that affects the amount of disruption caused - is support for a common level of representation in a unitary memory system.

But - variability effects could just grab attention and be explained that way. **Baddeley** (2000) - acknowledges the binding problem by adding a multi-modal episodic buffer - to try to account for the unitary nature of consciousness and address **Jones**.

Vocabulary acquisition

Role of phonological loop (PL) in learning new words. The ability to store sequences of phonemes when a new word is encountered and retaining its spoken form long enough to learn it is obviously important.

Neuropsychological evidence

Reduced capacity of PV's phonological store is good evidence PL plays a role in learning vocabulary. PV had normal LTM for familiar items but found it very difficult to learn novel word forms. **Baddeley et al** tested experimentally – learning of native language-foreign language (Russian) word pairs. No learning showed at all. However, if both words were native language (Italian) words performance was normal.

Finding demonstrates a distinction in the processes involved in learning the pairing types and shows a relationship between short-term phonological memory and long term phonological learning.

While KF's impairments show the dissociation between STM and LTM, PV shows there must be some association between the stores in the phonological domain.

Could be interpreted as showing short and long term phonological memory are difference aspects of the same system – i.e. PL as being an activated area within a phonological long term store – c.f. **Cowan**'s view of WM.

Individual differences

If learning new words depends on an individual's capacity to hold a phonological sequence over a short interval, the two capabilities should be correlated.

Children's auditory digit span corresponds to performance on vocabulary tests (**Baddeley et al**).

Non-word repetition (more demanding on phonological forms than digit span) is more highly correlated with vocabulary test scores than digit span.

And: **Gathercole et al** – found individual differences in the capacity of a child's PL predict performance on a simulated vocabulary learning task – so establishing the causal relationship to be this way around.

Measures of PL capacity also correlate with vocabulary in a second language – e.g. **Service** – Finnish children's ability to repeat English-sounding nonwords before learning English predicted their learning ability 2 years later.

Experimental studies

Papagno et al – adult learning of word-nonword and word-word pairs.

Increasing phonemic similarity of nonwords in a set, or number of syllables in nonwords impairs learning.

Corresponding manipulation of word-word pairs had no effect.

Also: articulatory suppression impeded word-nonword learning but no effect on word-word.

Results suggest role of the PL is specific to learning novel words.

Modelling the phonological loop

Models have been generated by several researchers as part of the effort to explain important findings the two-component model cannot – for example, such accounts of the PL say nothing about learning and long term phonological memory – they only address immediate recall – and even then it is not a complete account.

For example, digit span requires the order of the items to be remembered – and yet PL accounts do not explain how the order is encoded.

Moving to computational models from informal theorising means that models do not become inelegant and not testable (the two component model has been useful as it has able to generate testable predictions).

A computational model can only be barely adequate if it shows the same behaviour as a human does when presented with the same tasks. More powerful adequacy can be demonstrated if it is used to make predictions about novel experiments that are then subsequently shown to be borne out by the behaviour of human participants.

Serial order

What type of ordering mechanism does the PL use? Several hypotheses have been put forward.

(i) Chaining hypothesis - (e.g. **Jones, Wickelgren**): serial order formed by associations created between consecutive items. Problems with this explanation – (a) explaining recall of a sequence with repeated items. Although more difficult to recall in STM tasks, errors occur on rather than after the repeated item (**Jahnke**), and (b) – pattern of errors made in recalling sequences where phonemically similar items alternate with dissimilar ones. Zig-zag pattern – more errors on similar than dissimilar items; but dissimilar items recalled with same accuracy in alternating lists as in lists of only dissimilar items. Chaining theories suggest more errors ought to occur on dissimilar items as they follow similar cues.

(ii) Positional hypothesis – Order coded by associations between each item and a representation of an items position in the list. **Conrad** – verbal STM is an ordered array of slots – remembering the sequence is simply reading out the contents of the slots. Addresses problem of the same item being in two difference places in the list. Fails to account for typical order errors in serial recall – e.g. exchange of two adjacent items. The probability of such transposition errors decreases with distance from their

correct position. **Estes** - mathematical model proposed to account for this distribution of order errors - positional information encoded for each item that becomes less precise as a function of forgetting. **(iia)** Similar explanation in more recent computational models - **Burgess and Hitch; Brown et al** - order coded by associations and a timing signal that varies with position. Successful explains the zig-zag of phonemically similar and dissimilar items as recall is a two stage process - positional information first, followed by phonemic content. Phonemic similarity impairs the second stage but has no effect on the first. **(iii) Primacy model** - **Page and Norris**. A non-associative model. Differences in activation levels of items encode information about their order. Each successive item in a list has a lower level of activation than its predecessor - a 'primary gradient'. Can account for the zig-zag pattern. This model is similar to (iia) as its shares the two stages of recall but has different explanations as to how these stages work. The **temporal grouping effect** - presenting items rhythmically in groups helps recall - e.g. 318, 476, 205 recalled more easily than 318476205. Grouping also changes the pattern of the most common order error - from transposition to errors between corresponding positions in groups - e.g. from 318<u>67</u>205 to 31<u>6</u>, 47<u>8</u>, 205. This effect suggests a positional coding system, with position being encoded at different levels as an explanation. This presents problems for the **Page and Norris model** - as it encodes order on a single dimension (gradient) but supports (iia) - **Hitch et al**.		